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ENVIRONMENTAL ASSESSMENT STUDY BASED ON THE LIFE CYCLE OF SANJAI CHIPS PRODUCTS IN PAYAKUMBUH, WEST SUMATERA

KAJIAN PENILAIAN LINGKUNGAN BERBASIS DAUR HIDUP PRODUK KERIPIK SANJAI DI PAYAKUMBUH SUMATERA BARAT

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ABSTRAK

*Peningkatan produktivitas agroindustri keripik Sanjai turut berkontribusi terhadap meningkatnya emisi dalam proses produksinya. Penelitian ini bertujuan untuk mengevaluasi dampak lingkungan dari produksi keripik Sanjai menggunakan pendekatan Life Cycle Assessment (LCA). Penilaian dilakukan berdasarkan tahapan LCA, yaitu penetapan tujuan dan ruang lingkup, inventori daur hidup, serta penilaian dampak. Batasan sistem yang digunakan adalah **gate-to-gate**, mencakup tahap pengupasan, pencucian, pemotongan, penggorengan, pembuatan bumbu balado, pencampuran, dan pengemasan. Unit fungsi yang digunakan adalah 1 kg keripik Sanjai. Untuk menghasilkan 1 kg produk, dibutuhkan 2,01 kg singkong, 0,35 liter minyak goreng, 9,63 liter air, dan 2,61 kg kayu bakar, serta menghasilkan 9,63 liter limbah cair. Dampak lingkungan dianalisis menggunakan perangkat lunak SimaPro 9.4.2 dan metode CML-IA Baseline. Hasil menunjukkan bahwa 1 kg keripik Sanjai menghasilkan Global Warming Potential (GWP) sebesar 1,3619 kg CO_2 eq, Acidification Potential (AP) sebesar 0,0131 kg SO_2 eq, Eutrophication Potential (EP) sebesar 0,0740 kg PO_4 eq, dan Ozone Layer Depletion Potential (ODP) sebesar 8,09E-07 kg CFC-11 eq. Tahap penggorengan merupakan penyumbang dampak terbesar, yaitu 78,7% dari total emisi, terutama disebabkan oleh penggunaan minyak goreng. Penelitian selanjutnya disarankan untuk memperluas batasan sistem ke cakupan cradle-to-grave serta memasukkan aspek sosial dan ekonomi guna mendapatkan penilaian keberlanjutan produk yang lebih menyeluruh.*

Kata kunci : dampak lingkungan, keripik sanjai, life cycle assessment, simpaPro

ABSTRACT

The growing productivity of the Sanjai chips agro-industry contributes to increasing emissions along the production process. This study aims to evaluate the environmental impact of Sanjai chips production using the Life Cycle Assessment (LCA) method. The assessment follows LCA stages: goal and scope definition, life cycle inventory, and impact assessment. The system boundary is gate-to-gate, focusing on the production stages: peeling, washing, slicing, frying, seasoning preparation (balado), mixing, and packaging. The functional unit is 1 kg of Sanjai chips. For each kilogram of product, inputs include 2.01 kg of cassava, 0.35 liters of cooking oil, 9.63 liters of water, and 2.61 kg of firewood, with 9.63 liters of wastewater produced. Environmental impacts were analyzed using SimaPro 9.4.2 software and the CML-IA Baseline method. Results show that 1 kg of Sanjai chips contributes to Global Warming Potential (GWP) of 1.3619 kg CO_2 eq, Acidification Potential (AP) of 0.0131 kg SO_2 eq, Eutrophication Potential (EP) of 0.0740 kg PO_4 eq, and Ozone Layer Depletion Potential (ODP) of 8.09E-07 kg CFC-11 eq. The frying stage is the primary hotspot, contributing 78.7% of total impacts, mainly due to cooking oil use. It is recommended that future research expand the system boundary to a cradle-to-grave scope and include social and economic dimensions to achieve a more holistic sustainability assessment.

Keywords: environmental impact, life cycle assessment, sanjai chips, simapro

INTRODUCTION

The development of industries has had a positive impact, such as driving economic growth in Indonesia. However, its negative impacts cannot be ignored, particularly the potential emissions generated. The use of raw materials, energy consumption, and waste formation contribute to potential emissions. Industries must address these issues efficiently and appropriately (Han-wen *et al.*, 2022). According to Law No. 20 of 2008 concerning Micro, Small, and Medium Enterprises (MSMEs), two of the key principles of MSMEs are sustainability and environmental awareness. This serves as a driving force for industries to evaluate the life cycle of their products, not only in large-scale industries but also in micro, small, and medium enterprises.

**Coressponding Author*

According to data from the Department of Manpower and Industry (2023), there are 45 Sanjai chip businesses in Payakumbuh City, spread across various districts, including Payakumbuh Barat, Payakumbuh Utara, Payakumbuh Selatan, Payakumbuh Timur, and Lampasi Tigo Nagari. The growth of this industry is supported by cassava production in Payakumbuh City, which is one of the leading commodities in the agro-industrial sector. According to data from BPS West Sumatra (2022), Payakumbuh City is one of the major suppliers of cassava in West Sumatra Province, with production of 4,755.32 tons in 2020, 3,059.00 tons in 2021, and 3,437.00 tons in 2022. The development of the Sanjai chip industry not only brings economic benefits but also has the potential to contribute to environmental impacts. The potential emissions include energy use, raw materials, resource consumption at each life cycle stage, and the output produced, thus requiring activities to assess the potential emissions comprehensively and formulate improvement recommendations to reduce the emissions generated throughout the life cycle of Sanjai chips. A study by Perdana *et al.* (2024) applied the LCA method to assess the life cycle of banana chips, resulting in environmental impacts in the categories of GWP, AP, and EP, with a major hotspot identified in the production stage due to the use of cooking oil during the frying process.

LCA approach is required to consider sustainability aspects throughout the product's life cycle and to prevent the transfer of negative impacts from one stage to another (Hannouf and Assefa, 2017). ISO 14040 defines Life Cycle Assessment as an approach to assessing the inputs, outputs, and potential environmental impacts of a product throughout its entire life cycle. Emission quantities can be evaluated using the LCA approach. LCA can be used to identify the positive and negative environmental impacts of a process or product, identify opportunities for process and product improvements, and compare and analyze multiple processes based on their environmental impact. The LCA methodology consists of three main stages: defining the goal and scope, conducting inventory analysis, and performing life cycle impact assessment.

Based on the MSME principles emphasizing sustainability and environmental awareness, implementing LCA is a strategic step to minimize emissions, improve efficiency and productivity in Sanjai chips production, and ensure export feasibility and product competitiveness in the global market. This study is expected to provide insights into the environmental impacts generated throughout the life cycle of Sanjai chips, which can then be utilized to support the implementation of environmentally friendly industries.

MATERIAL AND METHODS

In this study, the data collected and utilized consist of both primary and secondary data. Primary data are obtained through interviews with companies and relevant stakeholders, while secondary data are gathered from company records, including information on inputs and outputs, raw material usage, additives, energy consumption, machinery, and equipment used at each stage of the Sanjai chips production process, as well as waste generated from production and previous research findings. The methodology follows the LCA framework outlined in SNI ISO 14040:2016 by conducting a life cycle inventory analysis of Sanjai chips and assessing environmental impacts (BSN, 2016).

Goal and Scope Definition

The determination of a functional unit is a crucial step in environmental impact assessment using the Life Cycle Assessment (LCA) method, as it provides a basis for normalizing all system inputs and outputs. In this study, the scope includes a cradle-to-grave system boundary, encompassing all stages from cassava cultivation, transportation, and the production process of Sanjai chips in MSMEs, to the distribution of the final product to consumers. The selection of the functional unit follows the guidelines for life cycle assessment reporting issued by the Indonesian Ministry of Environment and Forestry, which recommend weight-based units. Since Sanjai chips are produced and sold by weight, the functional unit used in this study is 1 kg of Sanjai chips. A similar approach was adopted by Puspaningrum (2024), who used 1 kg as the functional unit in her LCA study of cooking oil. In general, impact assessment using the LCA method includes defining the product to be assessed, establishing system boundaries, selecting a functional unit, and determining the environmental impact categories to be analyzed (BSN, 2016).

Life Cycle Inventory Analysis

The inventory analysis refers to SNI 14044:2017, which involves identifying the inputs and outputs throughout the life cycle of a product. In this study, inventory analysis was conducted through interviews and field observations using inventory questionnaire forms and data requirement forms provided by the company. The inventory analysis includes the process of data collection and data calculation. The collected data consists of prima. data obtained through direct field measurements and secondary data, which is material balance input-output data from company documents. The data input includes the flow of processes such as peeling, washing, slicing, frying, oil draining, Sanjai seasoning preparation, seasoning mixing, and packaging. Subsequently, an environmental impact assessment was conducted to evaluate the potential environmental impacts generated based on the results of the inventory analysis (BSN 2017).

Environmental Impact Analysis

The impact analysis was conducted using the SimaPro 9.4.0.2 software, with the impact calculation method based on the Centre of Environmental Science of Leiden University Impact Assessment (CML-2001-IA baseline). The CML 2001 method classifies impact categories into two groups: mandatory (baseline) impact categories, which are used in most LCA studies, and additional impact categories, which represent operational impacts (Menoufi, 2011). SimaPro is one of the LCA data processing software tools that uses matrices in the process unit modeling, containing datasets and databases for assessing the impact of a product (Silva *et al.,* 2019).

The environmental impact analysis will evaluate various impacts such as Global Warming Potential (GWP), Acidification (AP), and Eutrophication (EP). The LCA method is conducted based on the LCA framework in SNI ISO 14040:2016. The first stage, after defining the goal and scope, is the inventory analysis, which starts from the initial production process of Sanjai chips through to the packaging. The inventory data is processed using the SimaPro software to calculate the environmental impact generated. Conclusions are drawn based on the predefined goal and scope. In the interpretation stage, the hotspots are identified through the conclusion process, which helps determine the stages of production that generate the greatest impact and the impact categories that have the most significant role in environmental impact. The research stages are shown in Figure 1

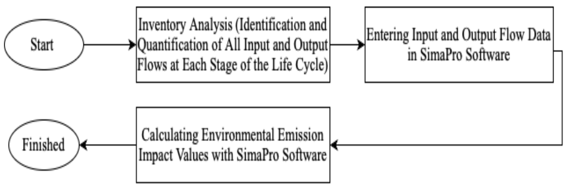

Figure 1. research stages

RESULTS AND DISCUSSIONS

Results of Sanjai Chips Production Observations

The scope of this LCA study on Sanjai chips follows a gate-to-gate approach, where the process begins with peeling the cassava skin, washing, slicing, frying, draining, preparing the Balado seasoning, mixing the seasoning, and ends with packaging. The system boundary analyzed in the production of Sanjai chips is illustrated in Figure 2. The impact categories assessed are selected based on their relevance to the agro-industry, namely Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Ozone Depletion Potential (ODP). These impact categories are also prioritized in the agro-industry sector as regulated by the Ministry of Environment and Forestry Regulation No. 1 of 2021.

The product analyzed in this study is packaged Sanjai chips, which are defined as the functional unit for environmental impact assessment calculations. The most common functional unit used for food products is based on mass (Phungrassami and Usubharatana, 2017). Therefore, the functional unit in this study is set as one package of Sanjai chips with a net weight of 1 kg to facilitate unit conversion processes. The determination of this scope is based on field observations and is aligned with the life cycle of Sanjai chips produced in MSMEs. The production process of Sanjai chips, as shown in Figure 2, will result in environmental impacts that will be quantified, specifically GWP, AP, EP, and ODP.

Inventory Analysis

The inventory analysis is based on data regarding the use of raw materials and energy in the production process of Sanjai chips. The inventory analysis links data to each unit process, covering both input and output data throughout the production process. The production of Sanjai chips begins with the peeling of cassava flesh using a peeler, where the outer cassava flesh is separated as solid waste. The next step is washing the cassava in a large basin of water to remove dirt such as soil or other unwanted particles. After washing, the cassava is sliced into thin pieces with a thickness of approximately 2–3 mm. This slicing process is performed using a semi-automatic machine equipped with rotating blades to cut the cassava. The sliced cassava is then deep-fried until it develops a crispy texture, which is a characteristic of Sanjai chips.

During the frying process, firewood is used as an energy source to heat the cooking oil in a frying pan. To reduce or eliminate excess oil, the fried chips are drained by allowing them to rest in a bamboo basket. The next step involves preparing the Balado seasoning, which consists of chili, garlic, and seasoning enhancers. This mixture is cooked using a wood fueled stove for 15 minutes. Afterward, the fried cassava chips and the Balado seasoning are thoroughly mixed to create the final Sanjai chips product. The final step is packaging the Sanjai chips into 5 kg, 8 kg, and 10 kg packages according to customer demand.

The mass balance is calculated based on inventory data, including input data such as the main raw material (cassava) and additional ingredients used for the Balado seasoning (chili, garlic, and seasoning enhancers). The output data include the final Balado-flavored Sanjai chips as well as by-products such as cassava peel waste. Other outputs include wastewater from the washing process and used cooking oil waste. The data collected from the Sanjai chips industry over one month are presented in Table 1.

Table 1 presents data collected from the Sanjai chips industry, which produces 6,702 kg of Sanjai chips per month from 13,500 kg of cassava. Based on the obtained data, calculations will be conducted using a functional unit of 1 kg of Sanjai chips.

The inventory data in Table 2 represents the raw material usage in the Sanjai chips production process, calculated for the production of 1 kg of Sanjai chips. These data are derived from the average total raw material consumption, additional ingredients, and energy usage over the course of one month. The inventory data collected over one month show that the production of Sanjai chips amounts to 6,702 kg. However, in this study, the impact assessment will be calculated based on 1 kg of Sanjai chips to facilitate unit conversion in the calculations. Table 2 presents the input data, which will be directly processed using the SimaPro software with the CML IA- Baseline method to estimate the potential impacts of Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Ozone Depletion Potential (ODP).

The production of Sanjai chips requires energy in the form of fuel, including firewood and cooking oil. The industry consumes 2,367 liters of cooking oil per month. The fuel used for frying consists of 17,550 kg of firewood. Electricity consumption in this industry is recorded at 127.8 kWh per month, which is used for cassava slicing machines, fans, lighting, water pumps, and blowers. The output data, as shown in Table 2, are adjusted based on the product quantity considered in the calculation, which is 1 kg of Sanjai chips.

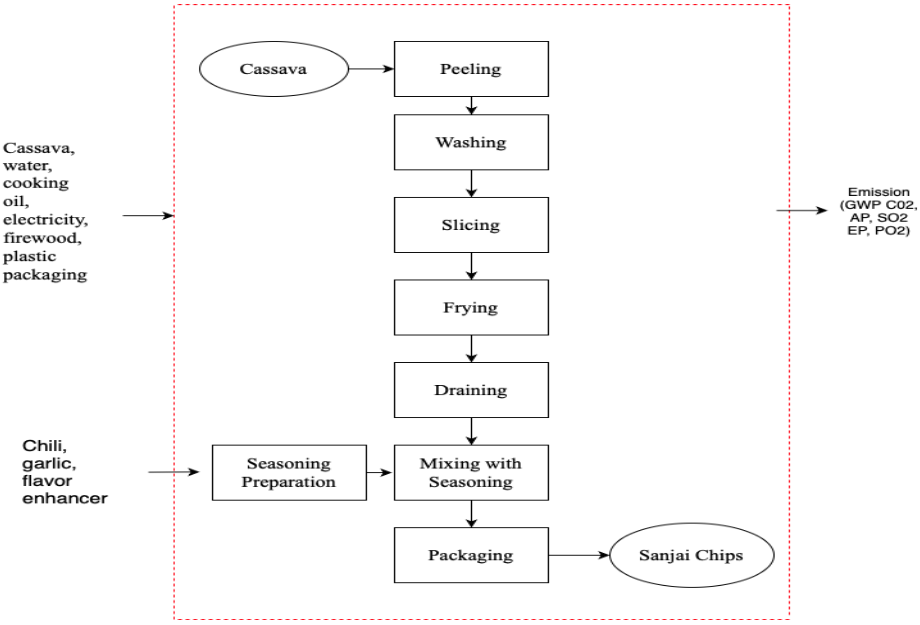

Figure 2. LCA System Boundaries for Sanjai Chips

Table 1. Data collection in the Sanjai Chips industry over one month

Data	Unit	Amount
Input		
Cassava	Kg	13,500
Chilli	Kg	432
Onion White	Kg	27
Flavoring	Kg	6,75
Cooking oil	Liters	2,367
Packaging plastic	Kg	26,73
Rope raffia	Kg	1,35
Water	Liters	64,557
Firewood	Kg	17,550
Electricity	Kwh	127,8
Output		
Chips Sanjai Ballad	kg	6,702
Skin of cassava	kg	801,9
Waste Liquid	Liters	64,557
Waste Cooking Oil	Liters	82,42

Table 2. Inventory data for the production of 1 kg of Sanjai Chips

Data	Unit	Amount
Input		
Cassava	kg	2,01
Chilli	kg	0,064
Onion White	kg	0,004
Flavoring	kg	0,001
Cooking oil	Liters	0,35
Packaging plastic	kg	0,0039
Rope raffia	kg	0,0002
Water	Liters	9,63
Firewood	kg	2,61
Electricity	Kwh	127,8
Output		
Chips Sanjai Ballad	kg	6,702
Skin ari cassava	kg	0,12
Waste Liquid	Liters	9,63
Waste Cooking oil	Liters	0,0123

Table 3. detailed impact values of sanjai chips production per 1 kg of Sanjai Chips

Process Stages	Input	Unit	Amount	GWP (kg CO_2 eq)	AP (kg SO_2 eq)	EP (kg PO_4 eq)	ODP (kg CFC-11 eq)
Production	**Input**						
	Cassava	kg	2,01	5,01E-15	3,49E-15	1,06E-15	7,14E-17
	Chilli	kg	0,064	3,52E-16	1,18E-15	8,37E-16	4,81E-19
	Onion White	kg	0,004	9,49E-23	1,31E-21	3,81E-22	1,44E-25
	Flavoring	kg	0,001	2,08E-17	9,57E-18	8,61E-18	3,30E-19
	Cooking oil	liter	0,35	2,58E-14	3,82E-14	4,59E-13	7,87E-17
	Packaging plastic	kg	0,0039	1,75E-17	8,86E-18	5,86E-18	6,24E-20
	Rope raffia	kg	0,0002	3,07E-16	1,65E-16	1,01E-16	1,31E-18
	Water	liter	9,63	0	0	0	0
	Firewood	kg	2,61	3,77E-16	1,15E-14	4,51E-15	3,41E-15
	Electricity	Kwh	0,01	5,74E-16	4,38E-16	9,30E-16	3,67E-19
	Output						
	Chips Sanjai Ballad	kg	1	0	0	1,48E-15	0
	Skin of cassava	kg	0,12	6,77E-17	2,72E-17	3,68E-17	6,14E-20
	Waste Liquid	L	9.63	6,65E-17	4,71E-17	2,75E-17	7,03E-19
	Waste Cooking Oil	L	0,0123	-3,42E-17	-2,09E-17	-1,68E-17	-7,44E-19

The inventory data collected over one month show that the production of Sanjai chips amounts to 6,702 kg. However, in this study, the impact assessment will be calculated based on 1 kg of Sanjai chips to facilitate unit conversion in the calculations. Table 2 presents the input data, which will be directly processed using the SimaPro software with the CML IA- Baseline method to estimate the potential impacts of Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Ozone Depletion Potential (ODP). The production of Sanjai chips requires energy in the form of fuel, including firewood and cooking oil. The industry consumes 2,367 liters of cooking oil per month. The fuel used for frying consists of 17,550 kg of firewood. Electricity consumption in this industry is recorded at 127.8 kWh per month, which is used for cassava slicing machines, fans, lighting, water pumps, and blowers. The output data, as shown in Table 2, are adjusted based on the product quantity considered in the calculation, which is 1 kg of Sanjai chips.

Impact Analysis

In this study, the calculation of emission values is based on a mass balance approach, aligned with the requirements to produce 1 kg of Sanjai chips. Four impact categories will be observed, namely Global Warming Potential (GWP), Acidification

Potential (AP), Eutrophication Potential (EP), and Ozone Layer Depletion (ODP). These four categories are the most relevant to the environmental impacts associated with the agro-industry of Sanjai chips production (PerMenLHK No. 1 of 2021).

Table 3 presents the results of the LCA analysis for 1 kg of Sanjai chips based on the four impact categories assessed in this study. The total potential Global Warming Potential (GWP) is 1.36E+00 kg CO_2 eq, the total Acidification Potential (AP) is 1.31E-02 kg SO_2 eq, the total Eutrophication Potential (EP) is 7.40E-02 kg PO_4 eq, and the total Ozone Depletion Potential (ODP) is 8.09E-07 kg CFC-11 eq. The use of cassava, cooking oil, energy sources (firewood and electricity), and plastic packaging contributes to the overall environmental impact. Among these impact categories, GWP is the most significant in the Sanjai chips industry. GWP results from human activities that release carbon compounds into the atmosphere through the consumption of natural energy sources, which have the potential to contribute to global warming over a 100-year timeframe (Ahmad *et al.*, 2019).

Global Warming Potential (GWP)

Figure 3 illustrates the contribution of materials (inputs) to environmental impacts. The use of cassava as the main raw material and cooking oil in the frying process are the most significant contributors to GWP emissions. Cassava contributes 5.01E-15 kg CO_2 eq, while cooking oil contributes 2.58E-14 kg CO_2 eq. This is due to the fact that cassava cultivation involves various inputs and outputs that generate emissions, including land clearing activities, chemical fertilizer application, and crop maintenance. A study by Perdana *et al.* (2024) indicated that the high GWP impact in banana chips production is primarily caused by banana cultivation, where emissions are generated from the use of chemical fertilizers and tractors. Similarly, the production of cooking oil involves energy consumption, raw material processing, and resource use, all of which contribute to GWP emissions.

Acidification Potential (AP)

Acidification is the process of acid deposition, commonly referred to as "acid rain," which occurs due to the reaction between sulfur dioxide (SO_2) and water in the atmosphere (Acero *et al.*, 2017). The acidification impact is caused by the release of pollutants such as sulfur dioxide (SO_2), sulfur trioxide (SO_3), nitrogen oxides (NO_x), nitric oxide (NO), and ammonia (NH_3), all of which contribute significantly to air pollution (Brilianty *et al.*, 2022). Figure 4 indicates that the use of cooking oil and firewood during the frying stage of Sanjai chips production contributes the most to the acidification potential (AP). The primary sources of acidification are industrial combustion and heating processes that release nitrogen oxides (NO_x) and sulfur oxides (SO_x). Additionally, gases such as ammonia (NH_3), nitrogen oxides (NO_x), sulfur oxides (SO_x), and hydrogen chloride (HCl) are recognized as key contributors to acid deposition and atmospheric pollution (Nematchoua, 2022). In the Sanjai chips agro-industry, the main contributors to AP are the use of firewood and cooking oil during frying. A study by Rizki *et al.* (2025) on the life cycle of palm sugar production found that firewood use significantly contributes to acidification potential. Similarly, LCA research by Perdana *et al.* (2024) on banana chips revealed that conventional frying processes involving cooking oil produce higher emissions contributing to acidification. The contribution of each input material to AP emissions is illustrated in Figure 4.

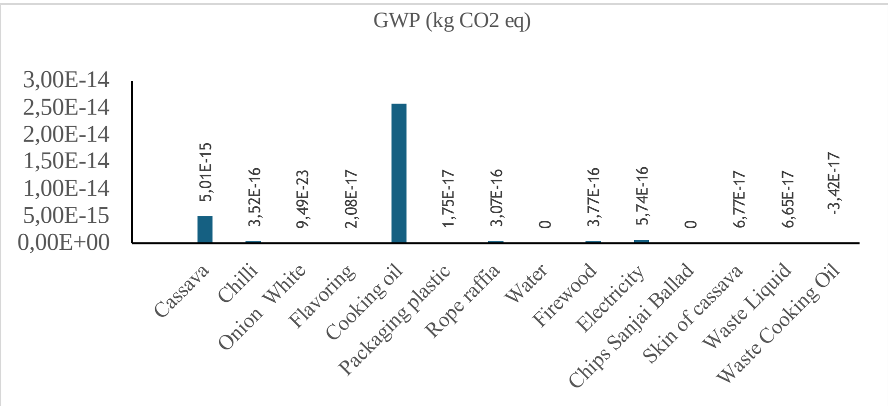

Figure 3. Contribution of material (input) usage to the GWP impact value

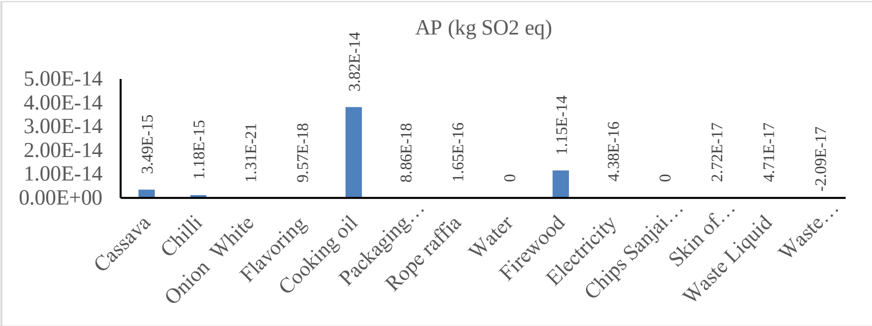

Figure 4. Contribution of material use (input) to the impact value of Acidification Potential (AP)

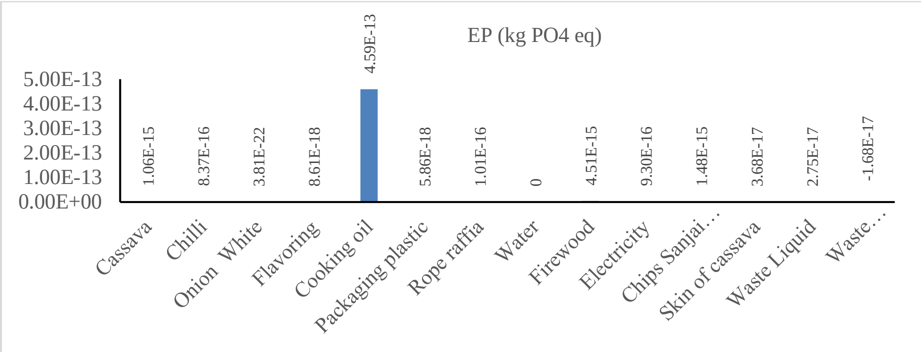

Figure 5. Contribution of material (input) usage to the impact value of EP

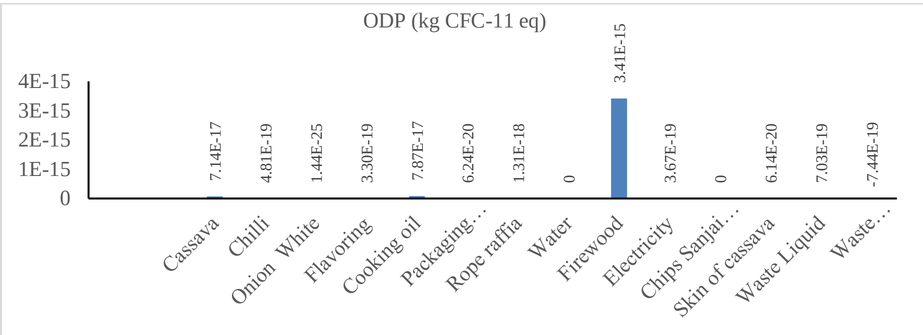

Figure 6. Contribution of material (input) use to the ODP impact value

Eutrophication Potential (EP)

Eutrophication is one of the impact categories assessed based on emissions equivalent to kg PO_4 eq. Figure 5 illustrates the contribution of the frying process to Eutrophication Potential (EP). In this process, cooking oil significantly contributes to EP due to its extensive life cycle, which spans from upstream to downstream stages. Each stage requires inputs such as raw materials, energy, and resources, while generating outputs that lead to emissions. A study by Perdana *et al.* (2024) found that the high EP impact in banana chips production is primarily caused by the use of cooking oil during the frying stage. This is consistent with the findings in this study, where cooking oil plays a major role in eutrophication due to its resource-intensive production and waste generation.

Potensi Ozone Layer Depletion (ODP)

Ozone Depletion Potential (ODP) is an environmental impact that leads to the thinning of the ozone layer in the atmosphere, calculated based on CFC-11 emissions (Yordan *et al.* 2023). The primary cause of ozone depletion is the increased concentration of chlorine- and bromine-containing gases, such as chlorofluorocarbons (CFCs) and halons, which are released into the atmosphere through human activities (Khaznah *et al.* 2024). Ozone depletion poses risks to human and animal health, as well as terrestrial and aquatic ecosystems. Figure 6 highlights the contribution of the frying stage, specifically the use of firewood, to ODP impact. This is due to emissions generated from burning firewood, which can influence ozone layer depletion. The contribution of input materials to ODP emissions is presented in Figure 6.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the analysis using the Life Cycle Assessment (LCA) approach, this study found that the production process of Keripik Sanjai generates emissions with the following impact values: GWP of 1.36E+00 kg CO_2 eq, AP of 1.31E-02 kg SO_2 eq, EP of 7.40E-02 kg PO_4 eq, and ODP of 8.09E-07 kg CFC-11 eq. The results indicate that cooking oil usage during the frying stage is the most significant contributor to emissions, accounting for 78.7% of the total impact. Therefore, improvement scenarios should be implemented to minimize emissions generated from sanjai chips production. Additionally, economic and social assessments are necessary to support the sustainability of the sanjai chips agroindustry.

Recommendations

Based on the results of the Life Cycle Assessment (LCA) analysis, it is recommended that the production process of Sanjai chips be focused on detailed improvements at the identified critical points (hotspots). These improvements may include switching to more environmentally friendly energy sources, increasing water use efficiency, and enhancing waste management to reduce pollution. Additionally, the adoption of energy-efficient production equipment, the selection of sustainable raw materials and packaging, as well as the capacity building of MSME actors through training on environmentally friendly production practices, are also essential measures. These improvements are expected to minimize environmental impacts while enhancing the overall sustainability of Sanjai chip production.

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